

L.J. Graham, R. Govan, R.K. Elsley, G. Lindberg  
Rockwell International Science Center  
Thousand Oaks, CA 91360

R.L. Randall  
Atomics International, Rockwell International  
Canoga Park, CA 91304

#### ABSTRACT

A multi-parameter measurement system was designed and built to process signals from acoustic emission (AE) transducers in real time. The system makes selected measurements of each detected AE event as it occurs and stores 23 measured parameters which describe that event in digital form on a standard diskette with IBM format. Measurements recorded on the diskette include information on the shape, magnitude, and frequency content of each AE burst, its timing with respect to location on the specimen under test and its timing with respect to load conditions, pressure, test time, and event count. Over 8000 AE events can be stored on a single diskette at a maximum instantaneous rate of 6000 events/sec and a maximum average rate of 1000 events/sec. Two floppy disk units are included in the system so one can be operational while the diskette is being changed in the other. After a specimen test, the data are transmitted to a remote minicomputer with a standard RS232 interface. Rapid analysis and display of the data by the computer has been demonstrated using up to 8 of the AE parameters at one time in a pattern recognition routine.

#### INTRODUCTION

Techniques for detecting acoustic emission events vary from one application to another, but they all use some form of transducer to convert one or more modes of surface displacement to an electrical signal. These electrical signals may or may not be accurate analog representations of the surface displacement of the item under test. This depends on the coupling for the various modes and the sensitivity to surface movements versus frequency for the particular transducer system. Whatever the limitations of the transducer system, if it is sensitive enough to reliably detect acoustic emission events from the item under test, the variations of the electrical signals from event to event may contain useful information about the nature, status, and location of the flaws in the test specimen.

It has been shown that several features of the acoustic emission signal can be used, on occasion, to separate events from different causes such as flaws of different types, sizes, and orientations, electrical disturbances and mechanical noise.<sup>(1-4)</sup> These distinctive features may depend upon the material being tested and the test conditions, and usually a considerable amount of laborious detective work is required to identify them. An event-by-event analysis of several features of the emission signal simultaneously, if it could be accomplished, would be useful. It would greatly reduce the amount of specimen testing and data analysis required to identify the characteristic features of the various sources of emission, if they exist, for a particular material. It could also allow a similar characterization of the emission sources during a structural test, where repetitive testing is impossible. Instrumentation which was developed to achieve this is described in the following sections.

#### BASIC MEASUREMENTS

We start here with the premise that the elec-

trical waveform from an AE event contains information about the source of the event that may be useful in evaluating the status of the material under test.

The most basic parameter we consider is the frequency content of the electrical signal from the transducer system. This may be strongly influenced by transducer related resonances and electrical filters in the signal amplifying and/or recording portions of the transducer system. However, if the transducer system is linear (no clipping of the signal waveform), variations of signal content from event to event may be measured. The range selected for the Rockwell AE characterization system was 20 kHz to 2 MHz.

Having established the frequency range, the next step was to select the various forms of amplitude measurements to be used. Digital means for recording many thousands of waveforms with 2 MHz bandwidth, 100 dB amplitude range, and event durations from microseconds to hundreds of milliseconds were apparently not economically feasible at this time. Therefore, analog techniques were selected for some basic amplitude measurements.

The first amplitude parameter to be selected was "peak value during event" on a log scale, in dB, from 0 to 100 dB, with 0 dB referring to a 1 microvolt signal level at the transducer.

Next, some form of envelope measurement was desired. The decision was made to utilize voltage to frequency converters and digital counters to measure the area under the envelope of each AE waveform. Sensitivity was set at 200 microvolt-microseconds per count with a capacity of 1,999,999 counts per event.

By this time we were getting down to the details of defining an "event." The decision was made to use a manually controlled discriminator with 79 discrete dB steps from 1.1 microvolt to 10 millivolts. A digital timer, monitoring the output of the discriminator, was specified to detect preset delays of 0.1 to 9.9 milliseconds

between threshold crossings. First the operator determined a discriminator threshold based on noise levels at the transducer. Next, the operator selected "rate delay," the minimum preset delay between threshold crossings in the same AE burst event. The start of an event is defined as the first threshold crossing after a quiet period exceeding the preset "rate delay." The end of an event is defined as the last threshold crossing preceding a quiet period exceeding the preset "rate delay."

Next, digital circuits were specified to measure on a logarithmic scale: the total number of threshold crossings (ring down counts) per event; the duration of the event; and the rise time of the event. Rise time is defined as the period from the start of an event to the time when the "peak" is detected. The scale selected for these measurements was 0 to 118 dB with 0 dB equal to 1 count or 1 microsecond, respectively.

A bank of 8-quarter decade filters was specified to separate the various frequency components in each event. Each filter output is monitored with a peak detector with 80 dB range. A filter bank amplifier preset by the operator, expands the full scale sensitivity of the peak detectors from 100 millivolts to 11 microvolts in 79 dB steps.

Additional digital circuits were specified to record: the event number, the time of the event to the nearest millisecond; the load value (or any other dc voltage parameter) at the time of the event; the time delay in microseconds from a second transducer channel (if used); the time delay from a reference "start of load" pulse (if used); and a manually preset "run" number.

Circuits were also specified to discard events; when time delays between two transducers (if used) exceed a preset value (2nd Channel Time Out); or when events occur before a preset "load start delay" and when events occur after a preset "load delay limit" (if load gating is used as in a fatigue test).

The block diagram of the system is shown in Fig. 1. Photographs of the system are shown in Figs. 2 and 3. A list of recorded measurements for each event is presented in Table I, along with four parameters which are constant during a given "run".

#### DATA RECORDING

The specified measurements total up to 32 bytes of data per event. The problem is to store these at instantaneous rates up to 150 microseconds per event and at average rates up to 1000 events per second.

The solution was to use standard floppy discs with a hardware controller that loads an entire track or 3328 bytes with each revolution of the diskette. The system writes or reads an entire 77 track diskette in as little as 14 to 15 seconds.

An internal buffer stores up to 128 events at rates up to 150 microseconds per event, while reading from or writing to the diskette at about 1 millisecond per event.

The floppy disc units can be used to format new diskettes, record test data or play back test data. Diskette capacity with standard IBM format is 8008 events. Two disc drives are included in the system so one can be operational while the diskette is being changed in the other. This minimizes lost data during operation.

#### COMPUTER INTERFACE

Connection to a remote computer is made using a serial interface. This RS232C type interface transmits data to a computer in 10 bit segments (8 data bits plus start and stop). At a rate of 9600 BAUD, 960 eight-bits data bytes are transmitted per second. At this rate it takes about 4½ minutes to transmit one diskette. The interface has selectable BAUD rates from 19,200 to 1,200.

#### DATA DISPLAY

Outputs are provided for transmission of selected measurements to the display unit during either the record or playback modes. The display system (not operational at the time this paper is being written) includes a "KIM" microprocessor unit, with extra memory, digital to analog converters and an analog CRT display. The display unit will be used to provide real time CRT display of up to four selected parameter distribution functions as data accumulates during a test or during off-line playback of the diskettes.

A front panel LED display is also provided to display, during record or playback, any one of the 16, 16-bit words recorded for each event. This display is useful for monitoring selected test variables during an experiment such as event count, test time, load voltage, or particular measurements such as rise time, peak, ring down counts, etc. The LED display also has a manual override to show disc controller status at any time.

#### DATA ANALYSIS

Analysis of the data proceeds in two steps. During a test, the monitor (when it is made operational) will display the differential distributions of one, two or four of the acoustic emission signal parameters as they build up during a test. Provision will also be made for plotting these curves on an x-y recorder at selected times to record the trends in the distributions with time. These parameters may be any of the measured features of the emission signals such as amplitude, energy, time of occurrence within a fatigue load cycle, etc., or they may be ratios of the primary parameters such as pulse shape (pulse duration/peak amplitude) or frequency spectral type (peak amplitude at frequency 1 peak amplitude at frequency 2). Real time observation of trends in these distribution functions are expected to provide valuable guidance in the more extensive post-test analysis using the minicomputer.

The types of data processing that can be done on the minicomputer are essentially only limited by the imagination of the experimenter. At present, software has been developed to perform all of the conventional acoustic emission data analyses such as plotting one emission parameter against another or against time or load level, and forming distribution functions from the experimental data (e.g., amplitude distributions). These plots may also be obtained for a sub-set of the total number of AE events based on a selected range of one or more parameters such as amplitude, frequency spectral type, risetime or location of the source of the AE. In addition, a multi-parameter pattern recognition routine has been developed which analyzes the data in an n-dimensional vector space and looks for regions of

high event density. Clusters of events in the vector space indicate a common "type" of event which may be associated with a specific source by other means (from prior knowledge, comparison with loading history, metallography, fractography, etc.).

An example of the usefulness of the pattern recognition capability is in identifying different frequency spectral types.<sup>(5)</sup> Acoustic emissions from a graphite-epoxy bend specimen were analyzed in terms of an 8-dimensional vector space where spectral amplitude in each of seven frequency ranges and the time of occurrence of each event were the eight parameters used. During the early part of the test, most of the emission events had the frequency spectral type shown in Fig. 4a. As the specimen was loaded to near its ultimate strength level and about 90 seconds before a major load drop occurred, emissions having the spectral types shown in Fig. 4b first appeared. This type of emission then occurred throughout the remainder of the test and showed up as a separate cluster of points extending along the time axis in the 8-dimensional vector space. The cause of the load drop was a lengthwise delamination between the specimen plies. If it can be established that the mechanism which causes the low frequency type of acoustic emission is uniquely associated with the delamination process, as is suggested by these initial results, this would be a tremendous aid in interpreting results of proof tests of composite structures.

Another comparison made in Fig. 4 is in the appearance of the frequency spectral data when obtained by two methods. The acoustic emission signals from a graphite-epoxy specimen were recorded on a modified videotape recorder<sup>(3)</sup> and then, during post-test analysis, the two emission signals were analyzed by playing them back through a standard swept frequency spectrum analyzer (Hewlett Packard Model 141S/8553B/8552A) and an x-y recording of the spectrum obtained, and through the present AEMPA system. The same was done for a region of electronic background noise immediately preceding each of the two emission

bursts in order to establish the relative amplitude levels obtained by the two methods. Comparison of the discrete and continuous spectral data shows that the two spectral types are easily recognizable by either method, and in fact a two-point spectral analysis would have been sufficient to separate the two types of emissions in this case.

## CONCLUSIONS

An Acoustic Emission Multi-Parameter Analyzer System which includes the very important parameter of frequency spectral content has been constructed and demonstrated. With this system, previously observed correlations between the characteristics of emission signals and specific emission sources can be more rapidly and quantitatively explored, and it is expected that previously unobserved correlations will be discovered. The practical result of these studies will be guidance in the design of structural test equipment and a better understanding of the results of such tests.

## REFERENCES

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TABLE I  
DATA RECORD SUMMARY

Measurement	Scale	ONB REF	Range
1. Run Number	Hexadecimal		0 to 15
2. Event Number	BCD Counts		0 to 8007
3. Event Time	BCD Seconds		0 to 9999.999
4. Analog Volts	BCD Volts		0 to 19.99
5. Peak Amplitude	BCD DB	1 $\mu$ V	0 to 99
6. Energy Counts	BCD 200 $\mu$ V- $\mu$ s/count		0 to 1,999,999
7. Ring Down Count	BCD DB	1 count	0 to 118
8. Event Duration	BCD DB	1 $\mu$ s	0 to 118
9. Event Rise Time	BCD DB	1 $\mu$ s	0 to 118
10. Filter Amplifier Overflow	1 bit Flag		0 or 1
11. 31.6 kHz Peak	BCD DB	10 $\mu$ V*	0 to 79
12. 56.2 kHz Peak	BCD DB	10 $\mu$ V*	0 to 79
13. 100 kHz Peak	BCD DB	10 $\mu$ V*	0 to 79
14. 177.8 kHz Peak	BCD DB	10 $\mu$ V*	0 to 79
15. 316 kHz Peak	BCD DB	10 $\mu$ V*	0 to 79
16. 562 kHz Peak	BCD DB	10 $\mu$ V*	0 to 79
17. 1 MHz Peak	BCD DB	10 $\mu$ V*	0 to 79
18. 1.778 MHz Peak	BCD DB	10 $\mu$ V*	0 to 79
19. Binaugulation Delay Time	BCD $\mu$ s		0 to +99,999
20. Load Gate Delay Time	BCD ms		0 to 99,999
21. Filter Amplifier Gain	BCD DB	Unity	0 to 79
22. Channel 1 Discriminator Gain	BCD DB	10 mV	0 to 79
23. Channel 2 Discriminator Gain	BCD DB	10 mV	0 to 79
2nd Channel Time Out	Decimal $\mu$ s		10 to 99,990
Load Start	Decimal ms		0 to 99,900
Load Limit	Decimal ms		0 to 99,900
Rate Delay	Decimal ms		0.1 to 9.9

\*Varies with filter amplifier gain.

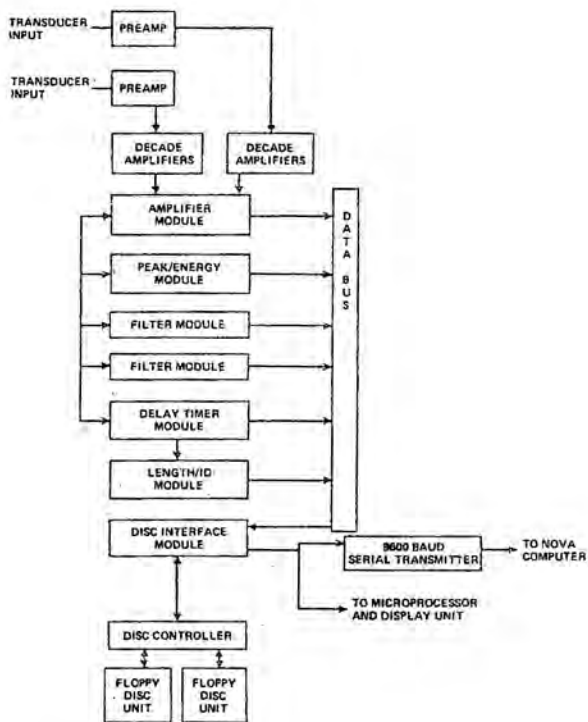


Fig. 1 Block diagram of AEMPA system.

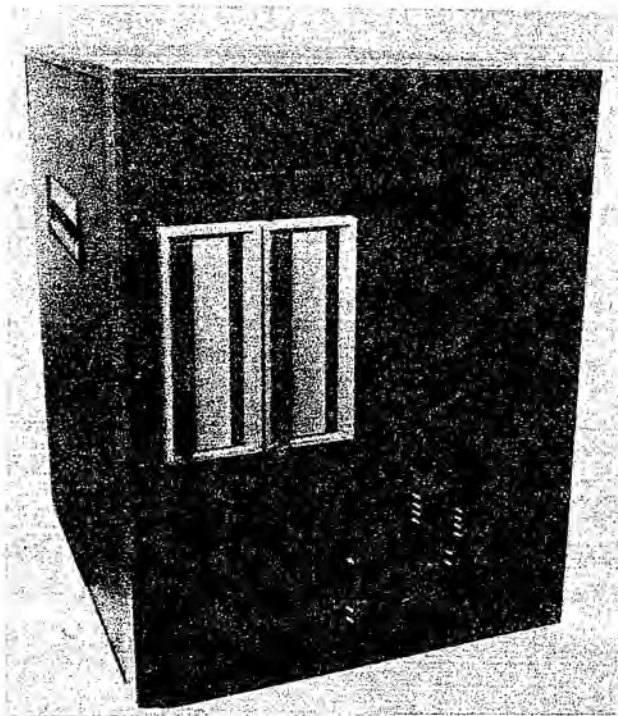


Fig. 2 Front panel layout.

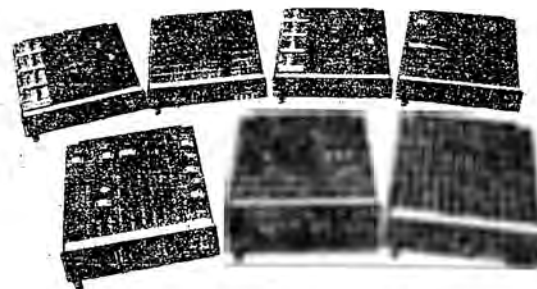
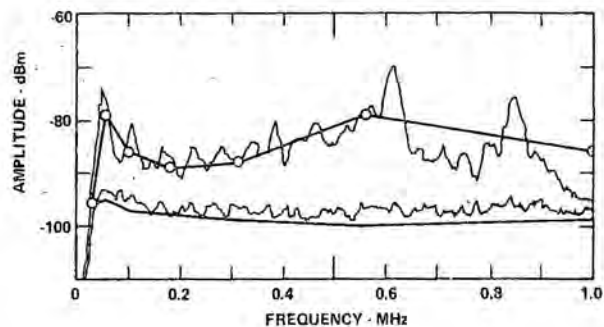
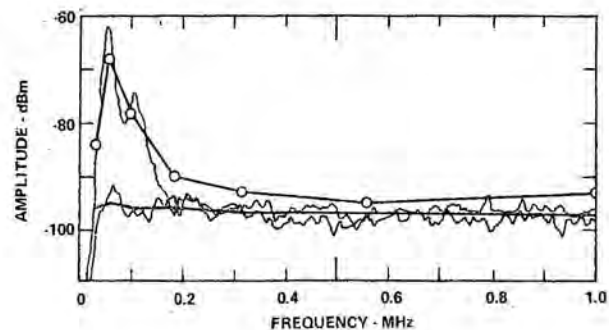


Fig. 3 Plug-in modules.



a



b

Fig. 4 Comparison of spectral analysis results.